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PRODUCING AND REPRODUCING FARMING SYSTEMS: NEW MODES OF ORGANISATION FOR THE SUSTAINABLE FOOD SYSTEMS OF TOMORROW

Modeling impact of Conservation Agriculture adoption on farming systems agricultural incomes. The case of Lake Alaotra Region, Madagascar

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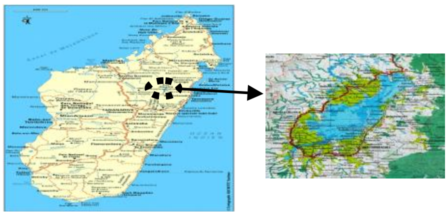
Summary

Conservation Agriculture (CA) was introduced at the lake Alaotra, in Madagascar, in the 2000's in a context of traditionnal mining upland agriculture and silting-up of lowlands rice fields. Land tenure pressure linked to the attractiveness of the area lead to the progressive colonization of surrounding upland hills (*Tanety*), very sensitive to erosion. Conservation agriculture tackles with a double challenges: i) maintain and/or increase household income and ii) preserve natural resources through sustainable agricultural practices in the long term. This paper assesses the economic impact of CA adoption on farmers's income trough modeling representative farms selected according to a local typology, based on the last 5 years with a prospective analysis for the next 5 years. The BV-lac Project Field database highlighted a light increase of yield according to the age of CA systems. A buffering effect on climate hazards has been as well identified trough production stability over the years leading to adoption as part of a risk limiting strategy. Elements of the CA techniques are adopted spontaneously within surrounding farming systems leading to improvment of conventionnal tillage based systems. Smallholders agricultural practices evolution displays a high capacity for innovation. Modeling with a dedidated tool (Olympe is a budget analysis oriented tool) has highlighted that CA systems improve significantly net farm income in the midterm (5 to 10 years) and gross margin at plot scale. For farm holdings with few irrigated rice fields, mainly relying on upland agriculture, CA systems increase farming systems resilience to climatic events and price volatility as well as sustainable agricultural practices maintaining local and fragile ressources.

KEY WORDS: Conservation agriculture, Madagascar, Lake Alaotra, adoption impact assessment, farming system modeling, resilience.

Introduction

The Lake Alaotra basin, surounded by hills between 700 to 1000 meters high, is one of Madagascar's "rice granary" with over 110,000 hectares of rice fields, known as the "Malagasy ". High population growth (doubling every 18 years) leads to an increasing pressure on natural resources. In such context, research has been associated to local development projects for the extension of agro-ecological techniques, based on the 3 principles of conservation agriculture (CA)[1]. The adoption of CA grew significantly since 2003 with the launch of the development project “BVLac”. 11 years after CA extension in the Lake Alaotra the paper intend to overview the outcomes of CA adoption and impact on farm income.



Map 1: the Lake Alaotra area in Madagascar

1 A new paradigm: CA as a response to agronomic, environmental and economic constraints

CA was introduced in the Lake Alaotra area in response to three major challenges: reducing poverty, feeding an increasing number of people, and reversing the degradation of the biophysical environment. The objective is more to develop a sustainable agriculture in opposition to traditional rainfed “mining” agriculture. The paradigm shift to CA is based on no tillage, combination of plants and rotation. The two main types of CA systems are based on dead mulch or with a cover crop. Expected advantages are: a significant reduction of water run-off (Findeling et al. 2003) and erosion (Lal, 2007) through permanent soil cover, resulting in an improved water balance (Scopel et al. 2004), an enrichment of the topsoil carbon and organic matter to maintain soil fertility in the long term (Corbeels et al. 2006). The cover crop also helps control weeds (Seguy et al. 2006). However, the benefits of these systems vary according to their conditions of application. The ecological balance is sometimes mitigated by: the frequent use of pesticides and herbicides, the need to adapt crop technical pathways to local practices, the management of soil-animal competition for biomass, the constraints on small family farms and low capital (Serpentié, 2009). CA has been promoted in a context of a “slow pioneer front” (Penot, 2009) in order to develop a regular and sustainable production (Domas et al., 2009). CA systems require an investment more or less consequent according to level of intensification (mineral fertilizers, herbicides, insecticides, equipment…) (Bolliger, 2006). Such investments are often essential to deal with hazards (weeds, mulch failures, parasites...). The majority of current CA surfaces of Madagascar are at Lake Alaotra, facilitated by a long term dynamic history of innovations (Serpentié, 2009). In 2007 are identified in the Lake Alaotra area a farm typology and a “Farming System Reference Monitoring Network” (FSRMN),(Durand et al, 2008). The table 1 presents a synthesis of CA systems distributed according to the plot physical situation and soils.

[1] The alternative agricultural practices that are being developed were by the Food and Agriculture Organisation of the United Nations (FAO) considered as a package, and labelled as ‘Conservation Agriculture’. These practices are: i) Continuous minimum mechanical soil disturbance., ii) Permanent organic soil cover and iii) Diversification of crop species grown in sequence or associations (FAO, 2010)

Table 1: Opportunities for cultural pratices applicable according to the physical environments (Domas et al., 2009)

Soil type and physical situation	Intensification level	Cropping Systems
Tanety rich (Upland)	All levels	▪ Intensive, cereal based (rotation maïze + legumes // rice) ▪ Extensive, based on fodder plants (*Styloxanthes spp*)
Tanety poor (Upland)	Low	▪ Extensive, based on fodder plants (rice on a long fallow) ▪ Ground legumes on mulch
PWCRF (Poor Water Control Rice Field in lowland)	All levels	▪ Intensive, cereal based (rice // rice) ▪ Extensive, with covercrops in dry season
Baiboho (upland with access to water in dry season through soil capilarity)	High	▪ Intensive, cereal based (rotation maïze + legumes // rice) ▪ Intensive rice production with winter vegetables (rotation legumes // rice//vegetables CS) ▪ Rice-vetch //rice-vetch ▪ Intensive system with one year *Stylosanthes guianensis* fallow

2 CA systems in the farms of Lake Alaotra

The adoption rate of CA practices after 2 years is a good indicator of farmers' interest in CA. From the 1000 ha declared as CA in BV-lac plot database, we identified 410 ha of real CA fields "stricto sensu" in 2010 (Fabre, 2010). The practice of CA does not necessarily make a farmer an "adoptant". Adoption is defined as the appropriation of knowledge and creation of a know-how by smallholders, built through a process of innovation and a learning process of 3 to 5 years. Between the first year of implementation of the CA systems (year 0 with tillage or Y0) and second (year 1 with no tillage Y1) the dropout rate is 60% in average varying from 34 to 70% (data 2005-2010, Fabre, 2010). Some farmers, characterized as "opportunists", are abandoning the system without having really experienced it between Y0 and Y1 and partially between Y1 and Y2 (around 45%). It is important to note that in year 1, Maize or rice yields are often lower or equivalent to conventional yields due to the change of practice and a partial management of CA techniques. In year 2, yields reach the same level as in conventional systems. From year 3 drop-out rate is lower (around 20%). Over the years the weed pressure might become too great and oftenly in year 5 or 6, farmers are forced to plow the fields (for soil compaction as well). Land tenure and share cropping are other causes involved in the abandonment of CA. In 2009/2010 only 11% of CA plots in the North-East are rented or sharecropped and 22% in the South East. In this context, it is easy to understand the relative reluctance of farmers to invest in sustainable CA systems, whose effects appear only after 3 years of investment (labor, technology, time, and inputs). Diffusion of CA at Lake Alaotra seems to be successful for some categories of famers when CA techniques bring solutions to specific constraints. However, we do observe that spontaneous diffusion of CA "stricto sensu" outside project is very limited .

3 Methodology

The methodology is based on an economical assessment of CA impact after introduction through a "counterfactual" approach based on: what would now be cropping systems if the farmer had not adopted the innovation? And comparison between CA and non CA farmers. Over a 10 year period, does the adoption of an innovative system allow for an increase of farm net income? Under what conditions? What are the different levels of adoption of conservation agriculture at the lake Alaotra?

The economic farm modeling tool Olympe has been used to manage this FSRMN and develop prospective analysis in order to test with different farms types potential improvements of their cropping patterns. Olympe (Penot, 2004, 2012) is a software, originally developed by Attonaty from the french INRA/ESR (Institut National de Recherche Agronomique) and co-developed with CIRAD and IAMM researchers (Institut Agronomique Méditeranéen de Montpellier). Olympe allow to built up farm structure and activities, identify cost and benefits per activity and calculate gross/net margin, income and balance at both plot and farm level. Olympe allow a prospective analysis on a step by step approach, with and without adoption of various types of technologies on crops, livestock or transformation activities. The objectives are to calculate the main economic farm indicators as well as labor use and cost.

Analysis of the FSRMN database (2007 to 2010) was performed in order to extract data on conventional cropping systems, crop sequences and pathway (Data from Olympe to Excel using a PivotTable). The coefficient of variation for each class in which the sample was large enough showed a high variability of data (greater than 30%). In addition, 37 farmers were surveyed in the suroundings to collect more information on conventional systems in order to identify reliable cropping patterns. We hypothesize that there are four levels of adoption of CA systems in the study areas: i) Level 0: traditional upland farming system, now assumed as very limited due to technical introductions since the 1930, ii) Level 1: conventional cropping system, including all innovations brought during the colonization and after the independence, iii) Level 2: Innovative Cropping Systems (ICS); it is the result of a partial spontaneous diffusion of CA techniques on conventionnal cropping systems and iv) Level 3: CA cultivation systems, popularized techniques are adopted and implemented fully or almost. Modelised farms are built from each farm type with the real observed rotation simplified in a rotation standard CA system over 10 years. Rotations or crop sequences by zones are chosen based on the actual rotation of the farm and its logic.

The counterfactual approach allow to simulate a farm with and without CA adoption where CA systems (current situation) were replaced by conventionnal systems (simulated situation). The modeling period is 10 years. Modeling is done with yields according to the last 5 climatic years. Olympe allows the comparison between CA and non CA farms on the following items : i) farm net income: to evaluate the economic performance of farming systems and ii) cash balance (after all family expenses) : it represents the theoretical capacity of investment (actual balance after subtraction of all farm and family expenses) and iii) cumulated cash balance over 10 years: to assess capital building capability in the medium term. The unit used in the analysis is the “activity system”, defined as a “farming system + a household” meaning that the total income includes off-far incomes. The Olympe module “production and price hazards” allows to test the robustness of any technical choices (CA or not CA) and to draw up prospective scenarios base on various prices or production levels. The modeling of standardized farms (according to the typology) take into account the diversity of situations

4 Economic analysis of CA system performance

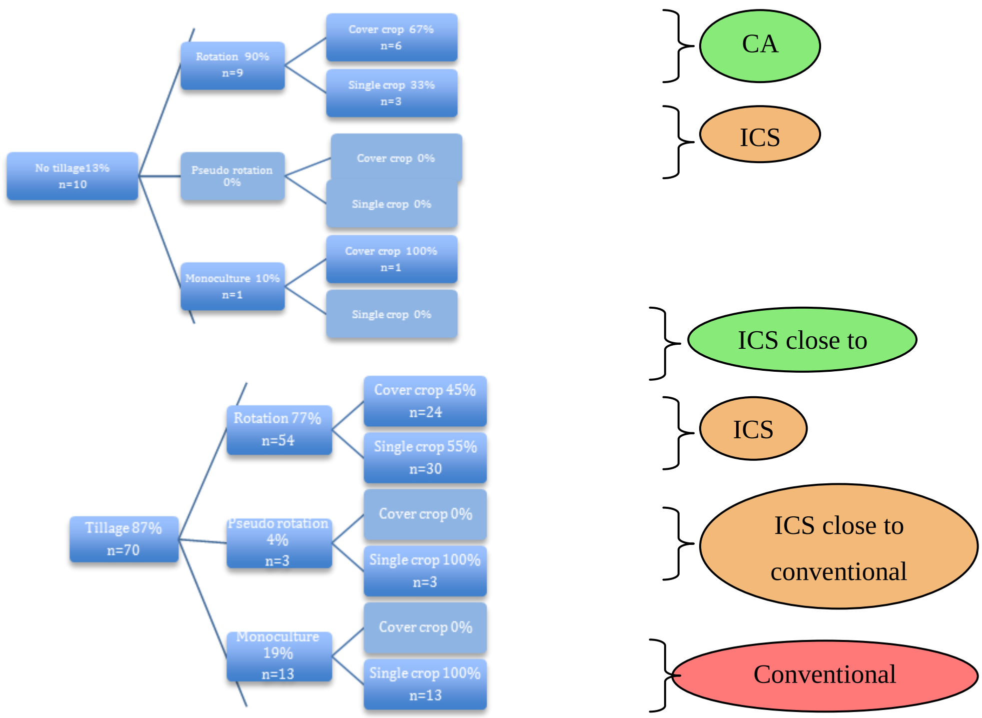
Due to the low intensification of all non-CA systems (low inputs), the climate remains the main factor limiting yields beside soils. CA yields evolve according to the age of the plot in CA as CA systems are less sensitive to climate (buffer effect of the much prooven by yields evolution from the projet plot database). The criteria used to define cropping systems are as follows: tillage or no tillage, rotation, pseudo-rotation or monoculture, absence or presence of mulch *in situ* on the plot. The results of the survey show a wide diversity of situations (the figure 1). Most tillage cropping systems have a rotation (77% against 19% in monoculture). 50 % combine agronomic rotations and soil cover. The covers are mostly covers of dead mulch on *baiboho*. Technical pathways with a monoculture or pseudo-rotation (two consecutive years with the same culture) are mostly in pure culture (no cover or combination of culture). In conclusion, farmers most often use the principle of rotation whether in tillage or no tillage. Based on these results, it is possible to define from the different combinations of practices what are the systems (conventional, ICS/(Improved Cropping Systems, CA) adopted by most farmers. The majority of surveyed plots are carried out spontaneously in hybrid systems : ICS (73 % of the plots): conventionnal systems with addition of some CA techniques. Conventional cropping systems have been therefore profoundly altered (contaminated) by development projects extension in Lake Aloatra. However, most farmers do not spontaneously adopt entirely CA systems “stricto sensu”. The table 2 below shows the standard rotations or crop sequence established from different rotations observed during surveys in 2011.

Table 2: Synthesis of disseminated CA systems and standard innovative systems per toposequence and per year

Toposequence	CA practices recommed by the project	Farmer ICS (Fabre,2010)	Spontaneous ICS (Enquêtes 2011)	Conventionnal (enquêtes 2011)
Tanety	Maize+leg.//upland rice (VSE, ZNE) Maize+leg.//upland rice // Maize+leg. //Groundnut (VSE, ZNE)	Maize + leg // maize + leg (ZNE) Maize+leg.//upland rice // Groundnut (VSE, ZNE)	Maize//maize// Groundnut (ZNE) Maize//maize// Groundnut //cassava (VSE)	Groundnut Cassava Maize Beans Tobacco (ZNE)
Tanety *Slope bottom*	Maize+leg./upland rice // Maize+leg. //groundnut (VSE, ZNE) Maize+leg.// upland rice (VSE, ZNE)	Maize + leg // upland rice // groundnut (VSE, ZNE)	Upland rice//maize// groundnut (ZNE) groundnut//cassava//beans (VSE)	
Baiboho	Upland rice+vetch – veg growing on mulch in dry season (VSE, ZNE)		Upland rice – veg growing on mulch in dry season (VSE, ZNE)	Upland rice – dry season veg. (VSE, ZNE)

This shows the strong innovative capacity of local farmers. This also shows that partial CA technologies do percolate through into cropping systems but generally not the entire CA technique as a whole.

Figure 1 : Cropping systems definied according to the combinaisons of practices

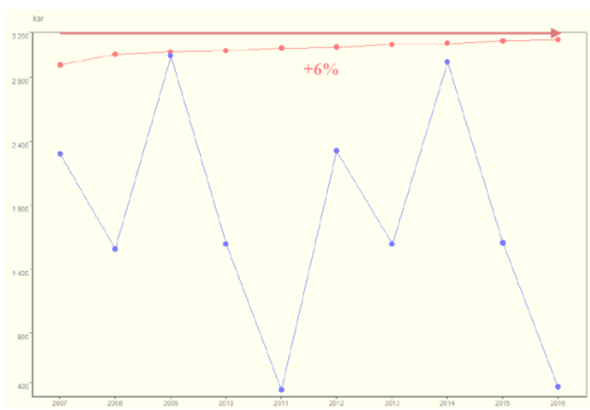


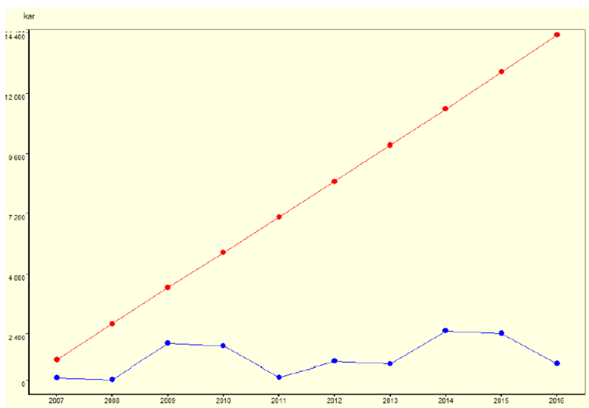
An example : a comparison on type D farms

Type D farm has 1.5 ha of PWCRF paddy fields with the following 5 years sequence: a good year with 2200 kg/ha, an average year with 1300 kg/ha, a very good year with 3000 kg/ha, again an average year with 1300 kg/ha and a disastrous year with 0 kg/ha (a maximum of 10% of the PWCPF plots are in CA; Macdowan, 2011). Upland crops are in CA. Between year 1 and 10, CA adoption do improve the net farm income of 6% overall (figure 2), directly related to increasing yields of upland CA rice and maize. This increase in itself is not significant over 10 years. The ICS system undergoes large variations of yields on PWCRF, which explains the variability of income.

Figure 2: Comparaison of farm net income with CA (red) and ICS systems (blue) for type D farm in VSE area

Figure 3: Comparison of the farm cumulated cash balance of ICS and CA systems for the type C farm in the VSE area





When PWCPF yield is 0, the farmer cannot meet his rice needs and will buy rice which will reduce the cash balance. In average years, his rice needs are sufficiently covered, but the sale of other products is limited and the farmer has a real cash flow problem, despite an additional off-farm income of 400 kar/year. The difference in cumulated cash balance (Figure 3) between ICS and CA systems is obvious after ten years: greater by 92%. However this difference is mainly due to the assumption of stable yields on PWCPF in CA if all plot are under CA. The non CA PWCPF does not allow the farmer to sufficiently capitalise given the yield and climatic variability. In CA system, capitalization is due to higher yields on upland surfaces since yields on PWCPF are considered stable. The intensification ratio in CA system remains at 8 (see table 3) showing that risk-taking for the overall conduct of the system is therefore very low. In contrast, the ratio in ICS varies greatly depending on climatic hazards. The table 3 presents the intensification ratio and the return to capital. A very bad year (year 5 and 10) the ratio indicates a moderate risk for the system (>30%). This risk is strongly influenced by the variability of rice production of PWCRF. The return to capital follows these variations in ICS. However, even in years 5 and 10 it is profitable to produce in ICS. In conclusion, the type D farm in ICS is viable even if its cash balance is negative on the bad years. Over 10 years the cumulated cash balance increases by 55% in total. CA systems meanwhile allow this type of farm to not only secure income by providing more regular rice production on PWCRF, but improves rainfed productions which become more stable over the years. Yield stability is the main output of CA adoption (when yield increase is provided by fertilizers).

For types D and E the total income the income increase over 10 years provided by CA adoption is significant relatively to other systems. CA systems secure net agricultural income. However, these types of farms do not have a high cash balance, stable enough to invest consistently in CA on upland. For the type D farm, agricultural net income from CA system is provided by the sale of rice produced on PWCRF (64% after self-consumption). For the type E farm: 46% of income is provided by PWCRF rice sales, 33% fom rainfed production and 21% from off-farm income. To intensify and improve income and cash flow, farmers must use a credit as a first step to change the cropping system to CA.

Unité	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Ratio intensification sur MB										
Modele type D SCV VSE 11	13	8	8	8	8	8	8	8	8	8
Modele type D Innov VSE 11 I	9	14	8	13	36	10	13	8	14	35
Retour sur investissement										
Modele type D SCV VSE 11	696	1 169	1 179	1 179	1 190	1 190	1 200	1 201	1 211	1 214
Modele type D Innov VSE 11 I	955	614	1 175	663	182	891	663	1 187	617	190

Table 3: Results of intensification ratio and return to capital over 10 years for the typ D farm in the VSE area

Conclusion

CA diffusion in lake Alaotra has evolved from a top-down approach focused on a “plot approach” (2004-2007) towards a "farming systems approach" (2008-2012), a holistic approach reinforced with the implementation of “farm counselling” since 2010. 450 hectares of effective CA in 2011 (estimated by Penot in 2012 from the 410 ha in 2010) can be considered as consistent given the complexity of the technique. From a qualitative point of view, the results are very positive with a strong spontaneous extension of ICS (71% for surveyed project farmers' plots). This expresses the innovative capacity of local farmers with knowledge and know-hows accumulated for more than half a century of innovation on rainfed crops. The typology of behavior showed that crop rotation is the most spontaneously adopted by farmers before the permanent cover of soil (especially the mulching of secondary season) and no-tillage. No-tillage clearly illustrates the paradigm shift associated with new practices. Punctual 'opportunistic" tillage is as well a common practice for CA farrmers as tillage seems to be the only recourse against soil compaction and weeds if the mulch failed. We observe as well a small but gradual increase in yields of rainfed crops in CA according to the seniority of the system, even with a low level of inputs since 2009. CA systems seem to buffer climatic hazards as shown by the regularity of production for most CA systems. Farmers today do not invest in chemical inputs anymore whatever systems since the doubling of prices of inputs in 2008. CA systems could however provide a solution in moving towards an ecological intensification of rainfed agriculture through the use of cover crops in order to secure and enhance investment in fertilizer in the very next future.The counterfactual analysis (in *ex-post* on the results of the 5 previous years and prospective in the next 5 years), showed that impact of CA systems on farm income is rather nuanced in a medium-term. The impact of CA on farm income *stricto-sensu* with important irrigated rice fields or PWCPF surfaces is poorly significant. The more upland crops, the greater impact with CA. The gradual silting of irrigated rice fields in the southeast, however, could in the future change this situation.

In the short term the impact of CA is not very significant for farms already economically viable (A, B, C and D). It takes at least a decade before measuring the cumulative effects at the farm level; even if the results appears significant rapidly at the plot level. This "lengthy time" is what is required for farmers to learn and consolidate their knowledge and know-how on these systems. The purely quantitative economic gain from CA sustainable agriculture is not obvious for farmers. Some farmers might not understand the basic principles of CA but do adopt CA to keep a link with the project and receive technical advice. The important development of ICS shows that if CA as a whole is difficult to manage and diffuse: the partial elements of the techniques "percolates" very well in conventional systems that then evolve into ICS. The continuum of systems from CA, ICS and conventional systems reflects the plasticity of local stratagies when existing techniques are modified to tackle farmer's contraints. It is perhaps too early to judge the real economic and ecological sustainability of these innovative systems. This trend, however, allows us to hypothesize that innovation is a strong local process that might boost ecological intensification in the long run. Finally, the major obstacles to CA adoption seems to be the paradigm shift from a short-term to a long-term vision of agriculture. Given the economic and political instability of the country, few farmers take the risk of waiting 10 years to observe the effects of CA on their income.

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